RESEARCH ARTICLE

Optimization of Hot Air Drying of Sweet Potato using Response Surface Method

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ABSTRACT: The use of response surface methodology in predicting the moisture content reduction and drying rate of dried sweet potato slices was the objective of this work. Freshly harvested sweet potatoes were washed and peeled. Experiments were performed at drying temperatures of 60, 70 and 80°C, slice thicknesses of 0.4 cm, 0.6 cm, and 0.8 cm, and drying times of 60, 180, and 300 minutes. The moisture content and drying rate values were optimal at a drying temperature of 70°C, slice thickness of 0.6 cm and drying time of 180 minutes. Treated sweet potatoes have the lower moisture content of 0.1809 g water/g solid at a temperature of 70°C, thickness of 0.6cm and drying time of 180 minutes compared to 0.3522g water/g solid. Treated samples require less time and temperature to attain optimum moisture content. The three factors influenced the drying process significantly. Minimized moisture content increased sweet potato shelf life. The ANOVA result showed that the response surface methodology gave a high correlation coefficient (R^2) of 0.9997 and 0.9987 for untreated and treated sweet potatoes, respectively.

KEYWORDS: Optimization, Sweet potato, ANOVA, Hot air drying

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1.0 INTRODUCTION

The goal of Response Surface Methodology (RSM), a blend of mathematical and statistical tools, is to optimize a response that is of concern and is affected by several variables in modeling and issue analysis [1,2]. The high efficiency, simplicity, and thorough theory of response surface approach make it an effective tool for optimizing many engineering applications. An optimization design saves a lot of stints and builds models precisely and rapidly [3].Planning and carrying out a series of tests to ascertain the effects of experimental variables on that system is known as experimental design. The collected data is divided into variances caused by the system itself and the corresponding uncertainties or errors that are always present in empirical data [4]. Face-centered composite designs have poor precision for estimating pure quadratic coefficients but very excellent quality predictions across the whole design range. They don't call for the use of points outside the initial factor range [5].The most typical response surface design is based on a factorial design. It effectively turns the cube of inference into a completely rotatable symmetric star by introducing center points and star points.

Food security and availability is a basic need for increasing Nigerians. Reduced food wastage is essential to increasing access to food, attaining food security, and lowering strain on natural resources. Around 1.3 billion tons of food are lost or wasted annually, according to the United Nations Food and Agriculture Organization [6]. Nigeria ranks 91st out of 102 countries due to its 37.1% food security index based on the food pillars [7].

Ipomoea batatas L., also known as the sweet potato, is the sixth-most significant food crop in the world. In 2009, there were 107.6 million tons of sweet potatoes produced worldwide. China, Uganda, Indonesia, India, and Japan are the top producers [8]. Nigeria, behind China and Uganda, is the world's third-largest producer of sweet potatoes in terms of output. 2.5% of the sweet potato crop in the world was produced in Nigeria in 2010. Sweet potatoes are still viewed as a minor crop in the nation, nevertheless [9].Raw sweet potatoes have modest quantities of other micronutrients including vitamins B_5,

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B_6, and manganese but are abundant in complex carbohydrate, roughage, and beta-carotene. As an inexpensive source of calories in particular, sweet potatoes have a long history of being used to prevent famine [10]. Millions of people in underdeveloped nations are fed by it, and farmers with limited resources particularly like it. Drying is required because fresh sweet potatoes' comparatively high moisture contents make them extremely susceptible to microbial deterioration.

Food material can only be dried if it has the right heat and mass transport properties. For equipment and process design and quality control, knowledge of the product's temperature and moisture distribution is essential [11]. Numerous studies have documented the significance of drying kinetics for a variety of agricultural products, including beans and chickpeas [12]. This research determined how temperature affects the amount and speed of moisture transfer between a product and its surroundings. Dried foods have a longer shelf life while still retaining most of their nutritional value [13,14].

Thin-layer drying models for sweet potatoes using tray dryers were demonstrated in earlier works [15]. Doymaz[16] investigated the impact of various infrared power levels (104, 125, 146, and 167W) on the kinetics of drying and rehydration of slices of sweet potato. After being dehydrated, sweet potato cubes' rehydration properties and structural alterations were examined [17]. On the quality of fried sweet potato chips, the impacts of pre-drying, blanching, and citric acid treatments were investigated [18]. Slices of carrots were hot air dried, and optimization, drying kinetics, and thermodynamic properties were investigated [19]. Slices of *Ganoderma lucidum* were optimized for convective hot air drying using a response surface approach [20]. Response surface optimization of the convection drying process for Persian shallot was investigated [21]. Optimum process parameters for activated carbon production from rice husk for phenol adsorption was investigated [22]. Evaluation of optimization techniques in predicting moisture content reduction in drying potato slices was studied [23].

The purpose of this research was to examine the relationship between the dependent variable (moisture content and drying rate) and the independent variable (drying temperature, slice thickness, and drying time).

2.0 MATERIALS AND METHODS

2.1 Sample preparation

The trials used freshly picked potatoes that were purchased from New Market in Enugu. To get rid of the filth, they were rinsed in clean water. The experiment made use of a hot air dryer. The samples were chopped into chips with varied thicknesses of 0.4 cm, 0.6 cm, and 0.8 cm after being peeled with a stainless knife. Some of the slices received pretreatment by being soaked in a 0.5% sodium metabisulfite ($Na_2S_2O_5$) solution for 5 minutes.

2.2 Experimental design matrix

Response surface methodology (RSM) of design expert software 11 was used to create the experiment. The Central Composite Design (CCD), face center, tool was utilized in the design process. Temperature, thickness, and time were taken into consideration as the factors, and the study's anticipated response was moisture content and drying rate. Table 2.1 displays the design matrix for the studies.

Table 2.1 Experiment design matrix

Std	Run	Factor 1 Temperature (ºC)	Factor 2 Thickness (cm)	Factor 3 Time (min)
9	1	60	0.6	180
16	2	70	0.6	180
8	3	80	0.8	300
5	4	60	0.4	300
18	5	70	0.6	180
12	6	70	0.8	180
19	7	70	0.6	180
4	8	80	0.8	60
14	9	70	0.6	300
2	10	80	0.4	60
15	11	70	0.6	180
6	12	80	0.4	300
13	13	70	0.6	60
20	14	70	0.6	180
1	15	60	0.4	60
3	16	60	0.8	60
17	17	70	0.6	180
11	18	70	0.4	180
7	19	60	0.8	300
10	20	80	0.6	180

Table 3.1 Response Surface Matrix for untreated Sweet Potato

Std	Run	Factor1 Temperature (°C)	Factor 2 Thickness (cm)	Factor 3 Time (min)	Response 1 Moisture content (gwater/gsolid)	Response 2 Drying rate (kg/m²s)
9	1	60	0.6	180	0.3420	0.00163
16	2	70	0.6	180	0.2706	0.00169
8	3	80	0.8	300	0.1390	0.00107
5	4	60	0.4	300	0.1261	0.00108
18	5	70	0.6	180	0.2706	0.00169
12	6	70	0.8	180	0.3387	0.00164
19	7	70	0.6	180	0.2706	0.00169
4	8	80	0.8	60	1.5620	0.00208
14	9	70	0.6	300	0.1136	0.00109
2	10	80	0.4	60	1.3240	0.00263
15	11	70	0.6	180	0.2706	0.00169
6	12	80	0.4	300	0.1390	0.00111
13	13	70	0.6	60	1.5320	0.00215
20	14	70	0.6	180	0.2706	0.00169
1	15	60	0.4	60	1.5420	0.00213
3	16	60	0.8	60	1.7640	0.00161
17	17	70	0.6	180	0.2706	0.00169
11	18	70	0.4	180	0.2330	0.00172
7	19	60	0.8	300	0.2121	0.00104
10	20	80	0.6	180	0.2240	0.00173

3.0 RESULTS AND DISCUSSION

3.1 Response Surface Methodology (RSM) Results

The Response Surface Methodology (RSM) results were reported in Tables3.1-3.2. The results of experimental moisture content and drying rate were calculated from the samples. The initial weight of the samples was recorded; the weight of the samples at different intervals of time, thickness, and temperature were collected. The change in weight of each sample divided by the final weight gave the moisture content. The change in mass of the sample divided by time and area of the sample gave the drying rate. Each table includes observational data on moisture content and drying rate under various temperatures, thickness, and drying time conditions.

The experimental results showed that increasing drying temperature decreases moisture content but high drying rate. The differences in water content between untreated and treated specimens can be associated with

structural changes in the treated specimens' configurations. The data of Tables 3.1-3.2 were transformed to obtain relevant information on the graphical analyses, mathematical models, and optima drying parameters. The moisture content and drying rate values were optimum at a drying temperature of 70°C, slice thickness of 0.6cm, and drying time of 180minutes. Treated sweet potatoes have a lower moisture content of 0.1809gwater/g solid at a temperature of 70°C, a thickness of 0.6cm, and a drying time of 180 minutes compared to 0.3522gwater/g solid. The structural composition of the treated samples was altered, which was responsible for the variations in moisture content of the treated and untreated samples. It collaborates with previous findings on the effect of inert particles on moisture content [19].

Table 3.2 Response Surface Matrix for Treated Sweet Potato

Std	Run	Factor1 Temperature (°C)	Factor 2 Thickness (cm)	Factor 3 Time (min)	Response 1 Moisture content (gwater/gsolid)	Response 2 Drying rate (kg/m²s)
9	1	60	0.6	180	0.2563	0.00186
16	2	70	0.6	180	0.1839	0.00192
8	3	80	0.8	300	0.1321	0.00117
5	4	60	0.4	300	0.1050	0.00118
18	5	70	0.6	180	0.1839	0.00192
12	6	70	0.8	180	0.3004	0.00182
19	7	70	0.6	180	0.1839	0.00192
4	8	80	0.8	60	1.8320	0.00192
14	9	70	0.6	300	0.1013	0.00119
2	10	80	0.4	60	1.5460	0.00259
15	11	70	0.6	180	0.1839	0.00192
6	12	80	0.4	300	0.0537	0.00121
13	13	70	0.6	60	1.5773	0.00251
20	14	70	0.6	180	0.1839	0.00192
1	15	60	0.4	60	1.6380	0.00237
3	16	60	0.8	60	1.7320	0.00216
17	17	70	0.6	180	0.1839	0.00192
11	18	70	0.4	180	0.1561	0.00193
7	19	60	0.8	300	0.1834	0.00115
10	20	80	0.6	180	0.1947	0.0019

3.1.1 Graphical Results of RSM

The graphical representations of the predicted versus actual moisture content of untreated and treated sweet potatoes are presented in Fig.3.1 and 3.5 respectively. Figures 3.2-3.4 and 3.6-3.8 show the three-dimensional graphs of the drying plots of moisture content against the studied factors of temperature, thickness, and time for the untreated and treated sweet potatoes, respectively.

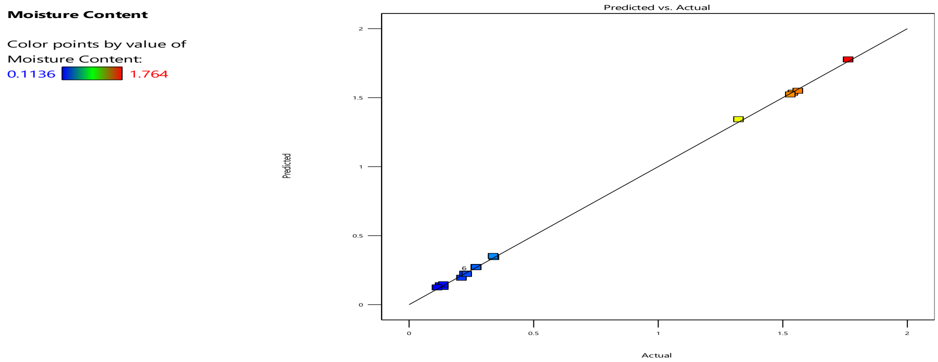

Fig.3.1 Predicted versus actual moisture content of untreated sweet potato

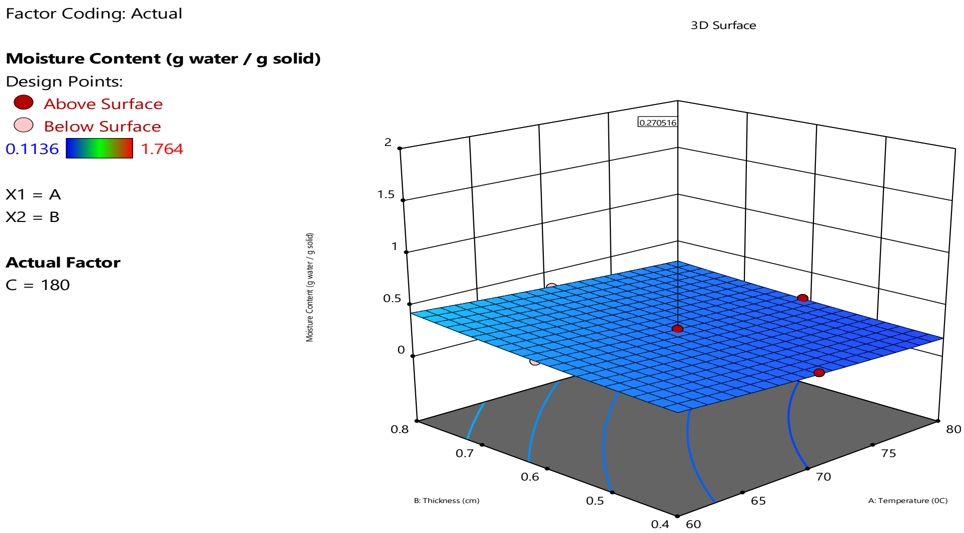

Fig.3.2 Moisture content versus Temperature and Thickness of untreated sweet potato

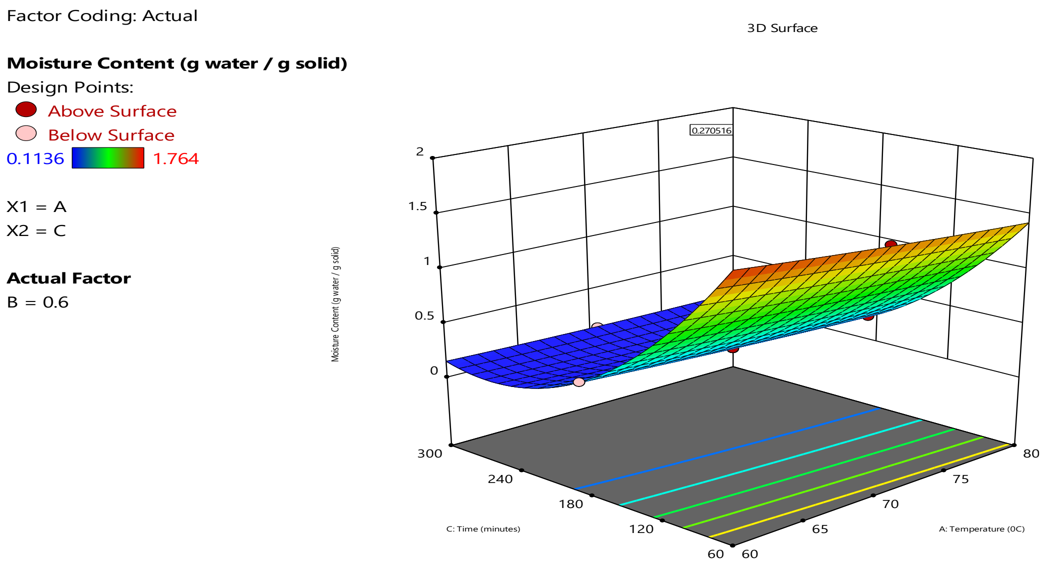

Fig.3.3 Moisture content versus Thickness and Time of untreated sweet potato

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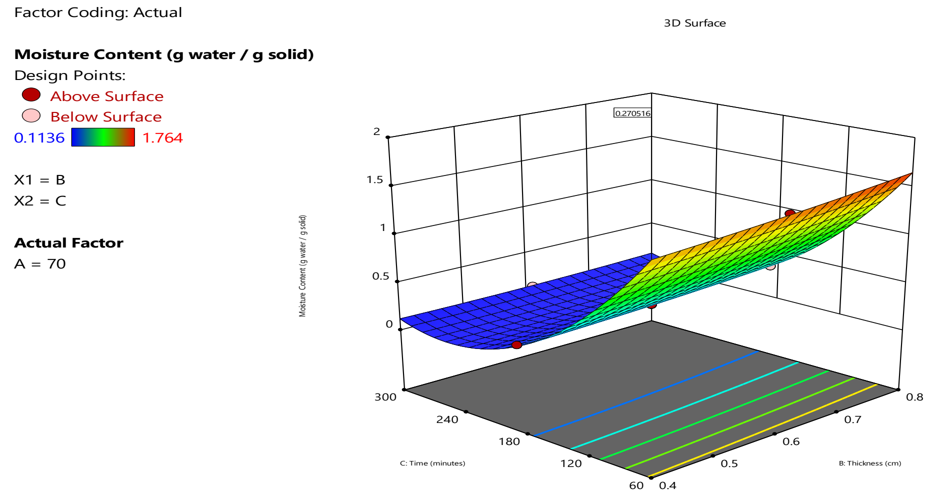

Fig.3.4 Moisture content versus Temperature and Time of untreated sweet potato

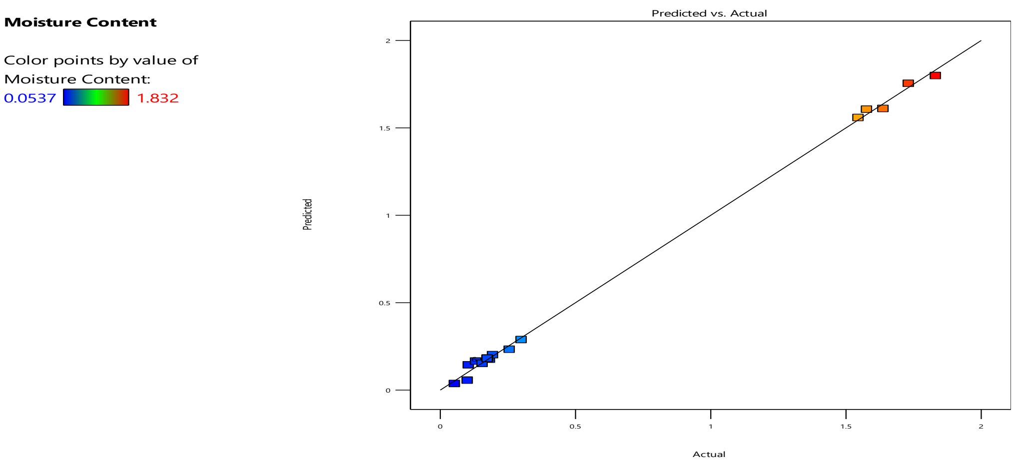

Fig.3.5 Predicted versus actual moisture content of treated sweet potato

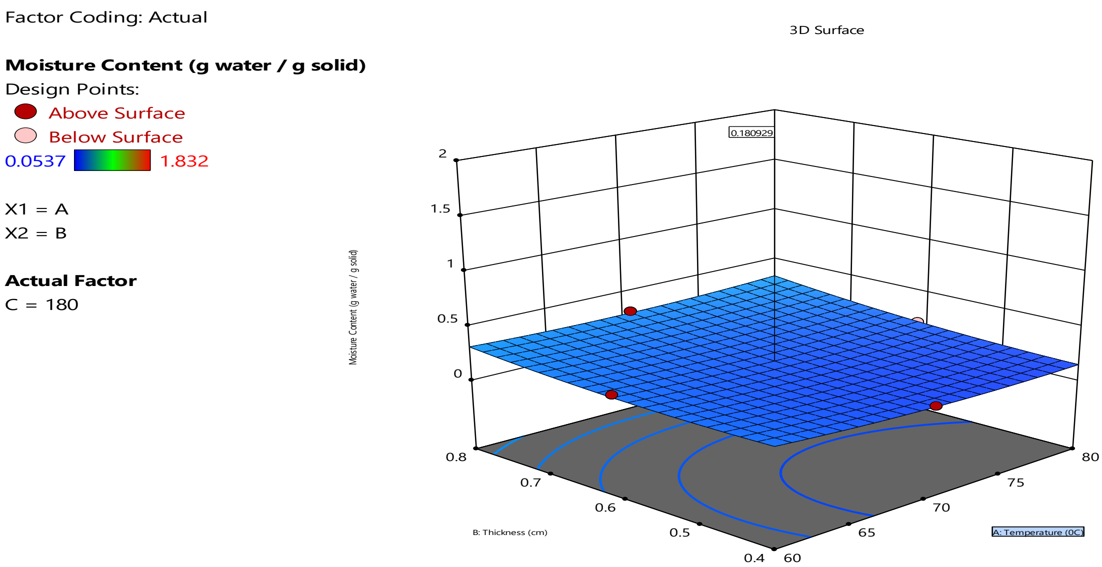

Fig.3.6 Moisture content versus Temperature and Thickness of treated sweet potato

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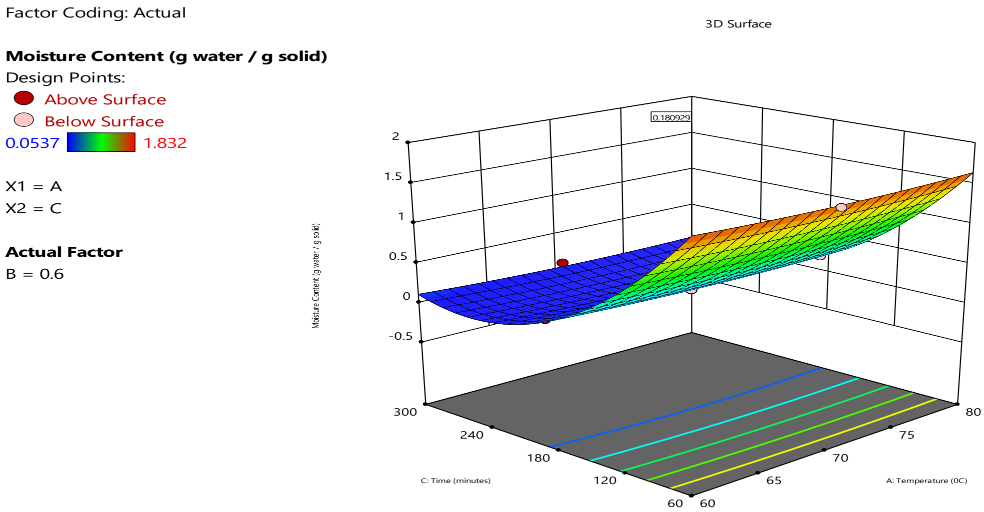

Fig.3.7: Moisture content versus Temperature and Time of treated sweet potato

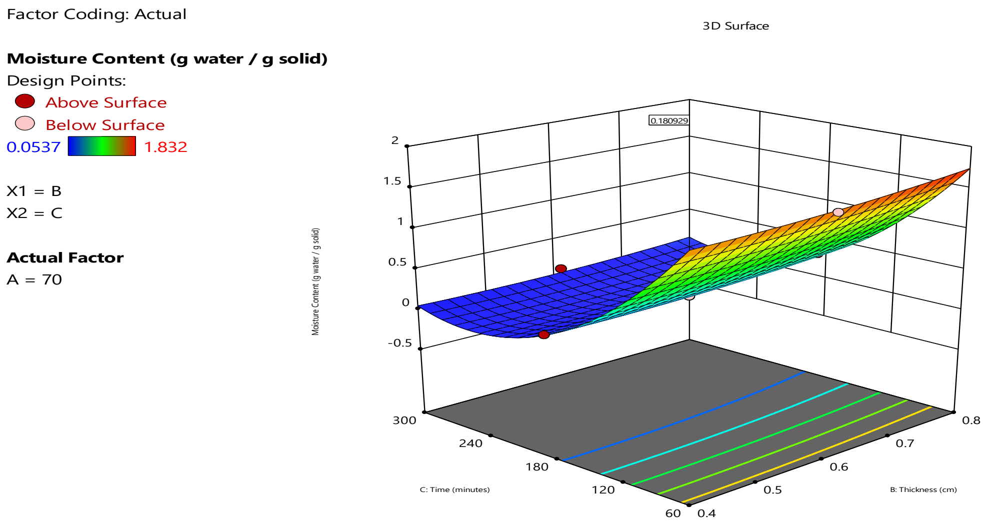

Fig.3.8: Moisture content versus Thickness and Time of treated sweet potato

The fact that the points clustered along the line of greatest fit suggests that the model can accurately reflect the samples' moisture content. The 3-D plots of moisture content against the factors taken into consideration revealed that each sample's moisture content depends on temperature, thickness, and time. With rising temperatures, longer drying times, and thinner samples, the moisture content reduces. The outcomes were comparable to earlier studies [24, 25].

3.2 Analysis of variance

Tables 3.3 and 3.4, respectively, give analyses of the variation in the moisture content of the untreated and treated sweet potato.

For untreated sweet potatoes, the Model F-value of 3832.91 in Table 3.2 indicates that the data are significant. If the P-value is less than 0.0500, then the model terms are significant. In this instance, A, B, C, BC, AC, and C^2 are significant. A difference of less than 0.2 separates the Predicted R^2 of 0.9947 from the Adjusted R^2 of 0.9994. The signal is appropriate, according to the ratio of 168.605. For treated sweet potatoes, the model's F-value of 1009.43 in Table 3.4 shows that it is significant. If the P-value is less than 0.0500, then the model terms are significant. The variables A, B, C, BC, and C^2 are important in this situation. The ratio of 81.5082 demonstrates that the signal is satisfactory. From the ANOVA Tables 3.3 and 3.4 for untreated and treated sweet potatoes,

the P-value is less than 0.05. It showed that temperature, thickness, and time had an effect on the drying of potatoes. The fact that the ANOVA report gave a high R^2 value means perfect correlation hence an adequate model [26, 27].

Table 3.3 ANOVA for Moisture Content of Untreated sweet potato

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	6.63	9	0.7363	3832.91	< 0.0001	Significant
A-Temperature	0.0358	1	0.0358	186.29	< 0.0001	
B-Thickness	0.0425	1	0.0425	221.10	< 0.0001	
C-Time	4.89	1	4.89	25466.59	< 0.0001	
AB	0.0006	1	0.0006	3.19	0.1045	
AC	0.0162	1	0.0162	84.24	< 0.0001	
BC	0.0175	1	0.0175	91.02	< 0.0001	
A^2	0.0004	1	0.0004	2.28	0.1623	
B^2	0.0007	1	0.0007	3.42	0.0941	
C^2	0.8392	1	0.8392	4368.67	< 0.0001	
Residual	0.0019	10	0.0002			
Lack of Fit	0.0019	5	0.0004			
Pure Error	0.0000	5	0.0000			
Cor Total	6.63	19				
Std. Dev. 0.0139		**R^2**	0.9997			
Mean 0.5608		**Adjusted R^2**	0.9994			
C.V. % 2.47		**Predicted R^2**	0.9947			
		Adeq Precision	168.6050			

Table 3.4 ANOVA for Moisture Content of Treated sweet potato

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	8.49	9	0.9433	1009.43	< 0.0001	Significant
A-Temperature	0.0024	1	0.0024	2.61	0.1372	
B-Thickness	0.0464	1	0.0464	49.64	< 0.0001	
C-Time	6.01	1	6.01	6427.25	< 0.0001	
AB	0.0046	1	0.0046	4.93	0.0506	
AC	0.0015	1	0.0015	1.64	0.2297	
BC	0.0062	1	0.0062	6.66	0.0273	
A^2	0.0035	1	0.0035	3.78	0.0806	
B^2	0.0041	1	0.0041	4.38	0.0628	
C^2	1.16	1	1.16	1241.95	< 0.0001	
Residual	0.0093	10	0.0009			
Lack of Fit	0.0093	5	0.0019			
Pure Error	0.0000	5	0.0000			
Cor Total	8.50	19				
Std. Dev. 0.0306		**R^2**	0.9989			
Mean 0.5429		**Adjusted R^2**	0.9979			
C.V. % 5.63		**Predicted R^2**	0.9833			
		Adeq Precision	81.5082			

4. CONCLUSION

Response surface methodology was efficient in predicting the optimum parameter of hot air dried sweet potato. The optimum moisture content of untreated sweet potato is 0.3522g water/ gsolid of 70°C, thickness of 0.6cm, and drying time of 180minutes. The optimum moisture content of treated sweet potato is 0.1809g water/gsolid at the same optimum conditions. ANOVA results showed that p-value

is less than 0.05 with high F-value. Correlation coefficient of 0.9997 and 0.9987 showed that it was an adequate model. Comparatively, treated samples require less time and temperature to attain optimum moisture content. Optimum process variables for the preservation of the food samples through drying were generated.

REFERENCES

[1] Myers, R.H., Montgomery, D.C., Anderson-Cook, C.M, 2009. Response surface methodology. 3rdEdition. John Wiley & Sons Inc. 705, 1-100.

[2] Nwabanne, J.T., Okpe, E.C., Asadu, C.O., Onu, C.E. 2017. Application of response surface methodology in phenol red adsorption using kola nut (*Cola acuminata*) shell activated carbon. Int. Res. J. Pure Appl. Chem., 15 (4) 1-14.

[3] Nazghelichi, T., Aghbashlo, M., Kianmehr M.H.2011. Optimization of an Artificial Neural Network Topology using Coupled Response Surface Methodology and Genetic Algorithm for Fluided Bed Drying. Computer and Electronic in Agriculture, 75 (1) 84 – 91.

[4] Makela, M. 2017. Experimental design and response surface methodology in energy application: a tutorial review. Energy Conversion and Management, 151, 630-640

[5] Leviska, L., 2013. Introduction to Experimental Design University of Oulu, Control Engineering Laboratory.1-10

[6] Gustavsson, J., Cedrtberg, C., Sonesson, U., van Otterdijk, R.,Meybeck, A., 2011. Global food losses and food and Agriculture Organisation (FAO) of the United Nation.

[7] FAO, 2016. Food and Agriculture Organizations. Agriculture and Consumer Protection. Dimensions of Need = staple. What do people eat. 1015.

[8] FAO., 2010. Food and Agriculture Organizations. Agriculture and Consumer Protection. Dimensions of Need = staple. What do people eat. 1015.

[9] Doymaz, I., 2004. Pretreatment effect on sun drying of mulberry fruits (Morusalba L.). Journal of Food Engineering, 65: 205–209.

[10] Internal Institute of Tropical Agriculture (IITA) 2015. Research Highlight for 1995. 53-54.

[11] Egbe, O.M, Afuape, S.O.,Idoko J.A., 2012. Performance of improved Sweet potato. American Journal of Experimental Agriculture 2(4) 573-586.

[12] Mohapatra, D., Rao,P.S., 2005. A thin layer drying model of parboiled wheat. Journal of Food Engineering, 66, 513-518

[13] Shafaei, S.M., Masoumi, A.A.,Roshan, H. 2016. Analysis of water absorption of bean and chickpea during soaking using Peleg model. Journal of the Saudi Society of Agricultural Sciences, 15,135-144.

[14] Ravinder., K.S., Sandeep., K., Mahesh, K., 2014. An experimental study on open sun drying of corn kernels. Int. J. Eng. Res. Technol., 2 (7) 1112-1119.

[15] Olawole, A.S., Omole, S.O. 2012. Thin layer drying models for sweet potato in tray dryer. Agric.Eng.Int: CIGR Journal, 14(2)1-9.

[16] Doymas, I, 2010. Thin-layer drying characteristics of sweet potato slices and mathematical modelling. Heat and Mass Transfer, 47(3) 277-285

[17] Ngankham Joykumar Singh., Ram Krishna Pandey, 2011. Rehydration Characteristics and Structural Changes of Sweet Potato Cubes after Dehydration. American Journal of Food Technology, 6, 709-716.

[18] Abdulla, G., El-Shourbagy, G.A., Sitohy, M.Z., 2014. Effect of pre-drying, blanching and citric acid treatments on the quality of fried sweet potato chips. American Journal of Food Technology, 9(1) 39 – 48

[19] Edeani N.J., Mbah, G.O.. Chime H.I., 2022. Optimization, Drying Kinetics and Thermodynamic properties of carrot slices in a hot air drying. International journal of advances in engineering and management. 4(1) 941-956.

[20] Chin, S.,Law, C.L. 2012. Optimization of convective hot air drying Ganoderma lucidum slices using response surface methodology. International Journal of Scientific and Research Publication. 2 (5) 1-11.

[21] Fealekari, M., Chayjan, R.A., 2014. Optimization of convective drying process for persain shallot using response surface method. Agric. Eng. Int. CIGR Journal 16(2) 157-166.

[22] Iheanacho, C.O., Nwabanne, J.T.,Onu, C.E., 2019. Optimum process parameters for activated carbon production from rice husk for phenol adsorption, Curr. J. Appl. Sci. Technol., 36 (6)1-11,

[23] Onu,C.E., Igbokwe, K.P., Nwabanne, T.J., Nwajinka, C.O., Ohala, P.E., 2020. Evaluation of optimization techniques in predicting moisture content reduction in drying potato slices. Artificial Intelligence in Agriculture.4, 39-47

[24] Aneke, N.A.G., Mbah, G.O. Edeani, N.J. 2018 Response surface methodology for optimization of hot air drying of water yam slices. International journal of scientific and research publication, 8 (8) 239-248.

[25] Zhang, L., Wang, B., Zhang, L.2014. Optimization of hot air drying of purple sweet potato using response surface methodology. International conference on Mechatronics, Electronic, industrial and control engineering. Atlantis Press pp 719-723.

[26] Tufeku, S., Ozkal, S.G., 2023. Optimization of Hybrid (Microwave-Conventional) drying of sweet potato using response surface methodology. Foods.12(16) 3003

[27] Moloto, P.I., Mosala, M. Omolola, A.O.,Jideani, A.I.O., Laurie S.M., 2021. Optimization of hot air drying on functional properties of flour from dried South African sweet potato cultivars using the response surface methodology. Food Science and Technology. 41(1)39-46.